Heavy Flavor Results from PHENIX

Timothy Rinn (Iowa State University)

For the PHENIX Collaboration

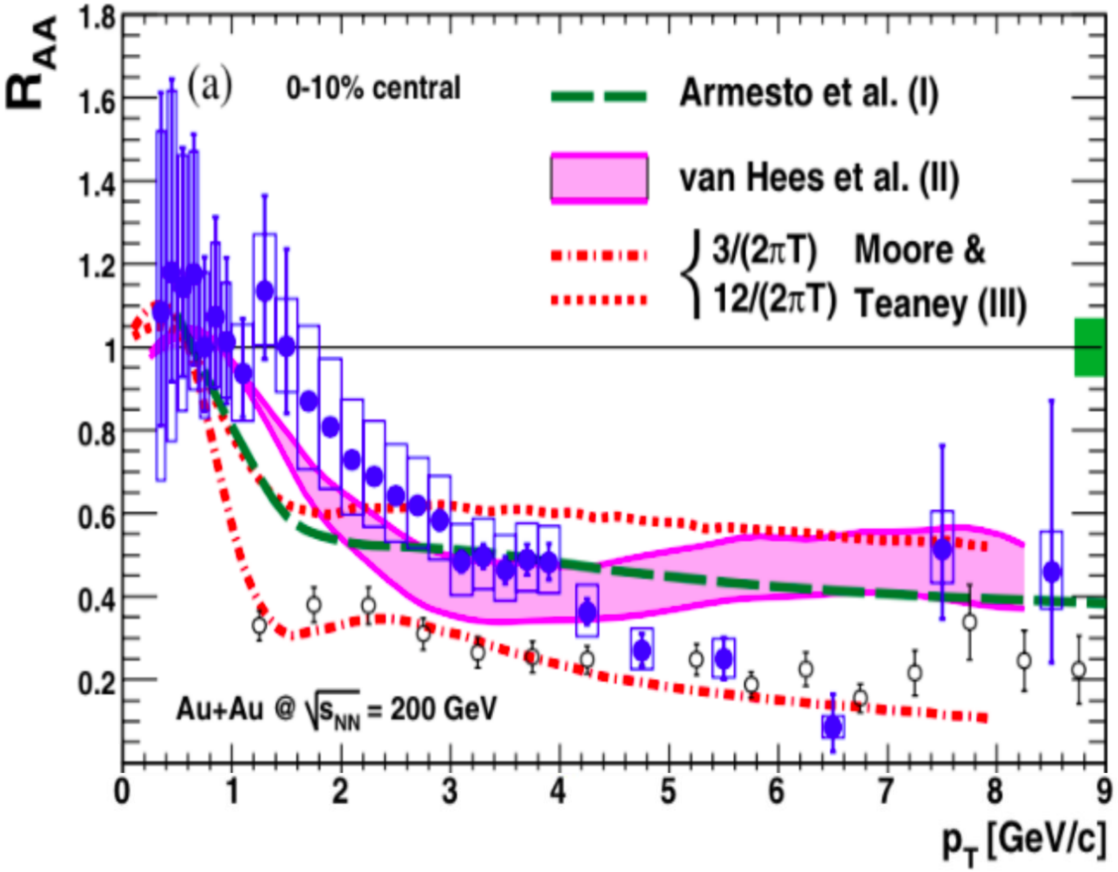
Outline

- Measurement of single electrons from charm and bottom decays at mid rapidity in Au-Au collisions at 200 GeV using the VTX (*Phys. Rev. C* ***93****, 034904 (2016)*)

- New Preliminary $B \rightarrow$ J/ψ measurement at forward rapidity in 200 GeV Cu-Au

Measurements of Single Electrons from Charm and Bottom decays:

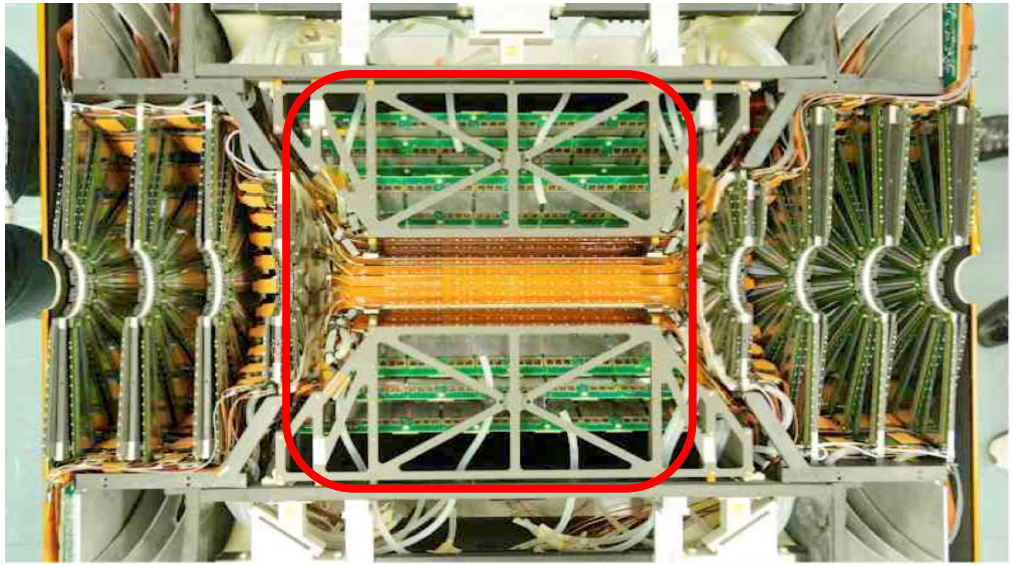
Phys. Rev. C ***84***, *044905 (2011)*



Single electrons from inclusive heavy flavor decays have been shown in previous results to be strongly suppressed in Au-Au collisions

The high-p_T regime is expected to be dominated by electrons from bottom

PHENIX Silicon Vertex Detectors (VTX, FVTX)



- The Silicon Vertex Tracker (VTX) is located in the central arms and has 4 layers between r = 2.6 and 16.7 cm.
  - Inner two layers are silicon pixels with 14.4 μm resolution
  - Outer two layers are silicon strips

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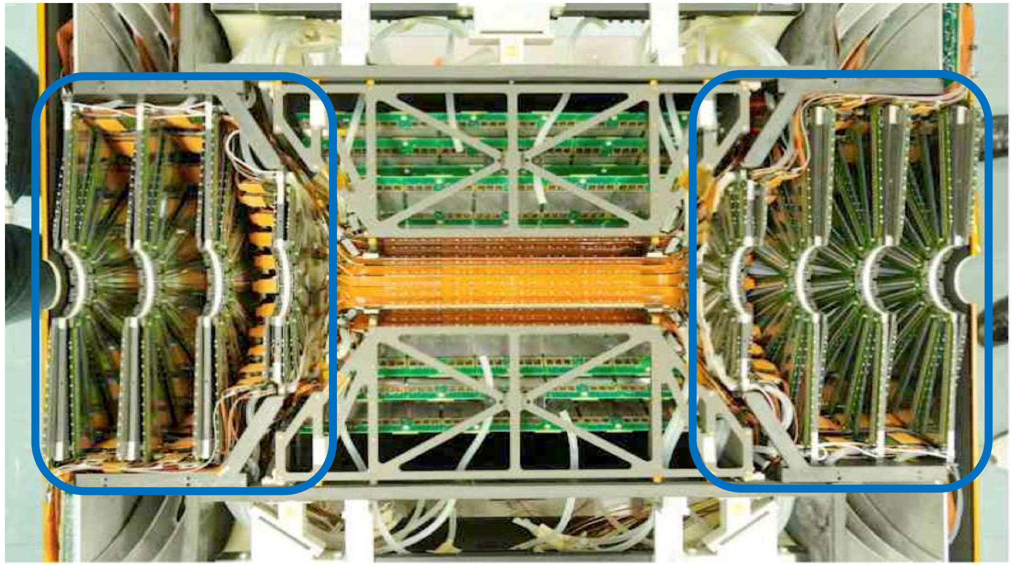

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  - Inner two layers are silicon pixels with 14.4 μm resolution
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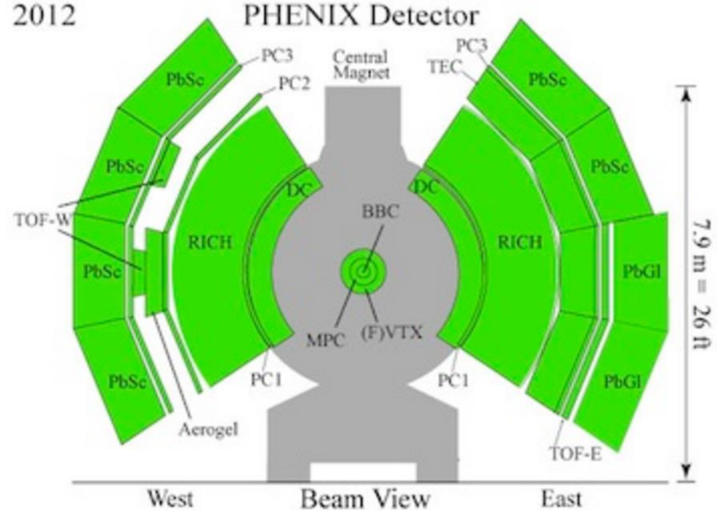
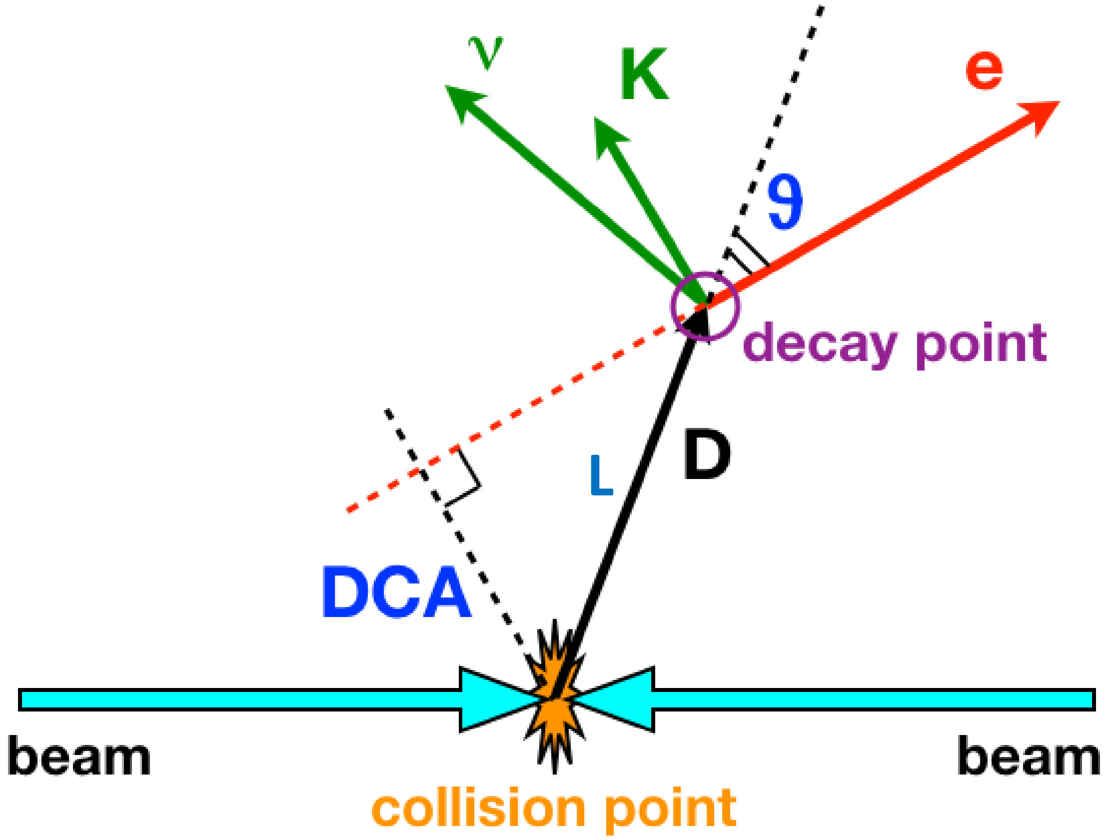
- The Forward Silicon Vertex Tracker (FVTX) is located in the north and south muon arms and has 4 layers between z=20 and 38 cm.
  - Provides accurate measurement of radial distance

Electrons at Mid Rapidity



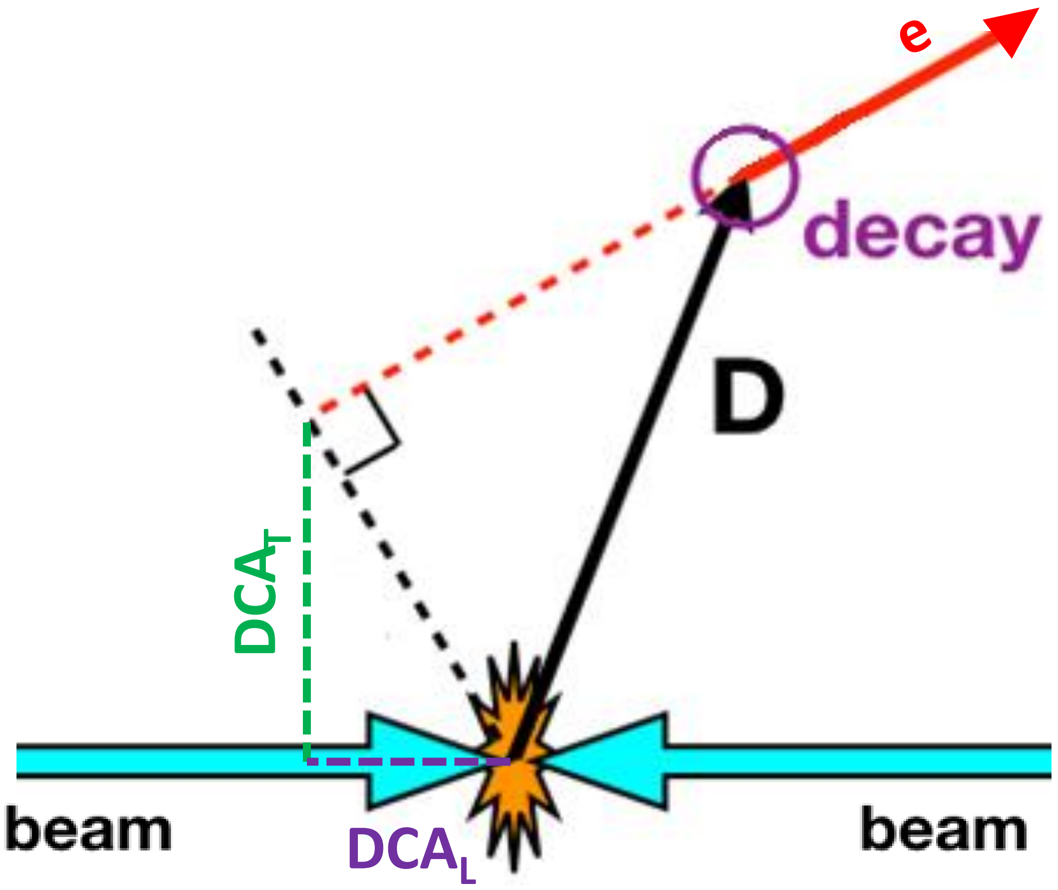


Semileptonic decays of both bottom and charm hadrons produce displaced electrons

The decay length of bottom hadrons is larger than that of charm hadrons (L in the figure shown)

The Distance of Closest Approach (DCA) of electron tracks was measured using the VTX

Displaced Electron Tracking using the VTX

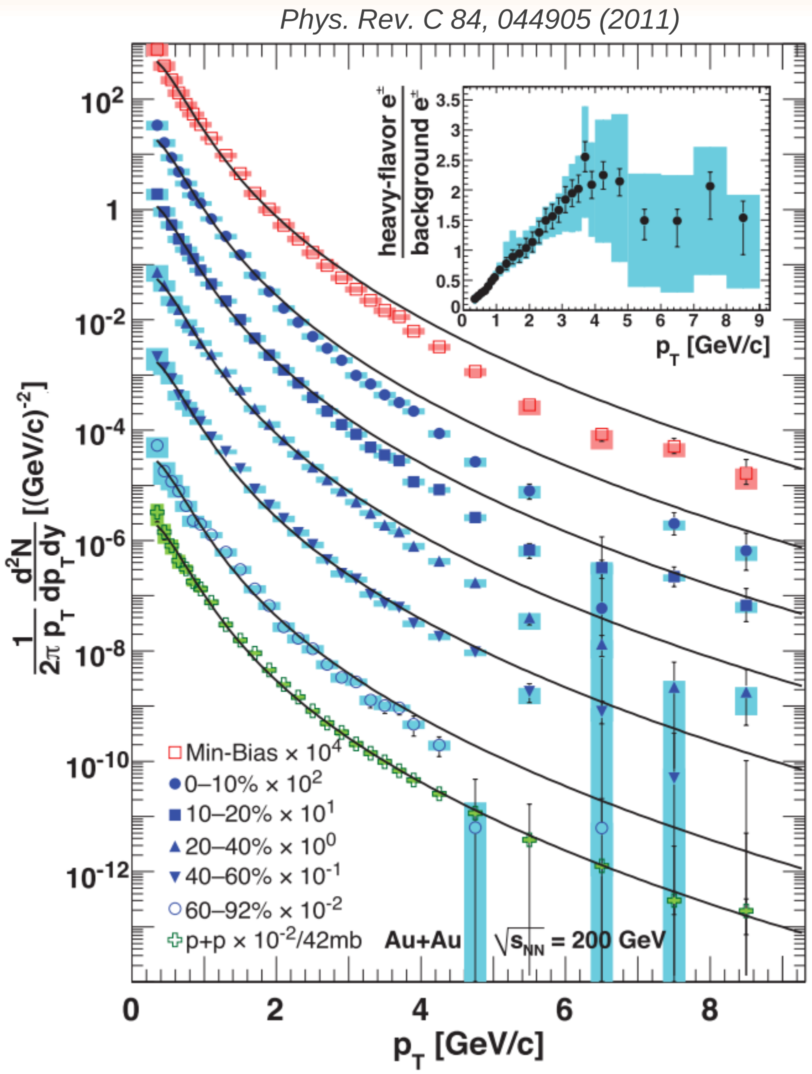


Calculate the Distance of Closest Approach (DCA) of an electron track to the collision vertex

The DCA is calculated separately in the transverse (DCA_T) and Longitudinal (DCA_L) planes

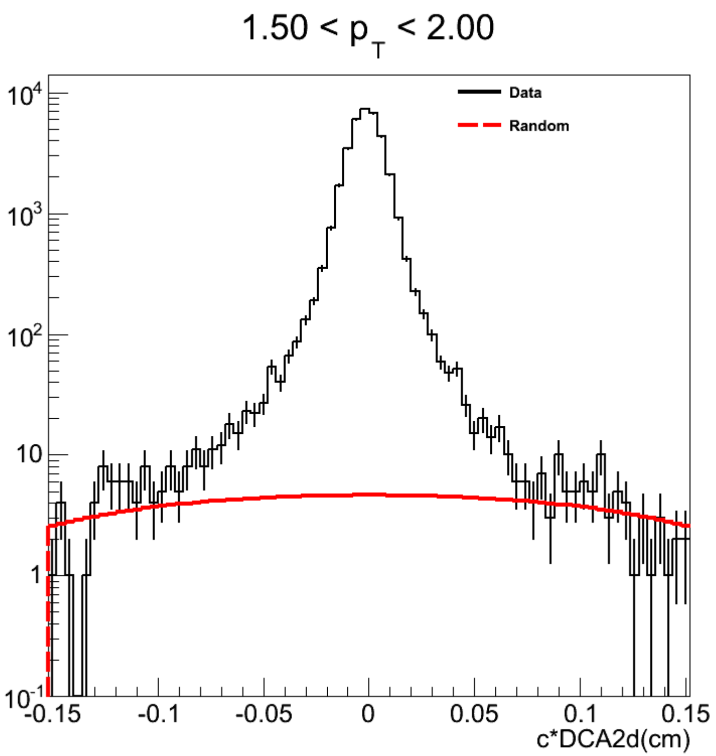
DCA_T Resolution about 60 μm

Analysis Strategy



- 2 part analysis:
  - Used previously published invariant yield of single electrons from heavy flavor decays
  - Measured DCA_T of electrons, taking advantage of the different decay lengths of the D and B mesons
- Used Bayesian unfolding to simultaneously take both parts into account in the analysis

DCA_T Distributions: Backgrounds

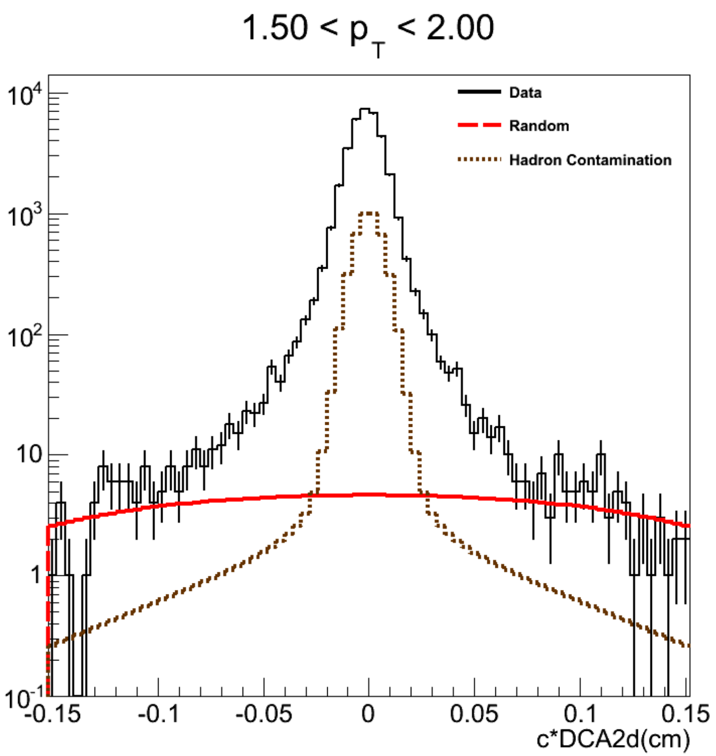


*Phys. Rev. C **93**, 034904 (2016)*

- Measured Electron DCA_T for the Run 11 (2011) data set.
  - Used 5 p_T bins between $1.5 < p_T < 5$ GeV

<u>High-Multiplicity Bkg.</u>
Data driven shape
Tracks with large DCA_L

DCA$_T$ Distributions: Backgrounds



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Data driven shape
RICH Swap Method

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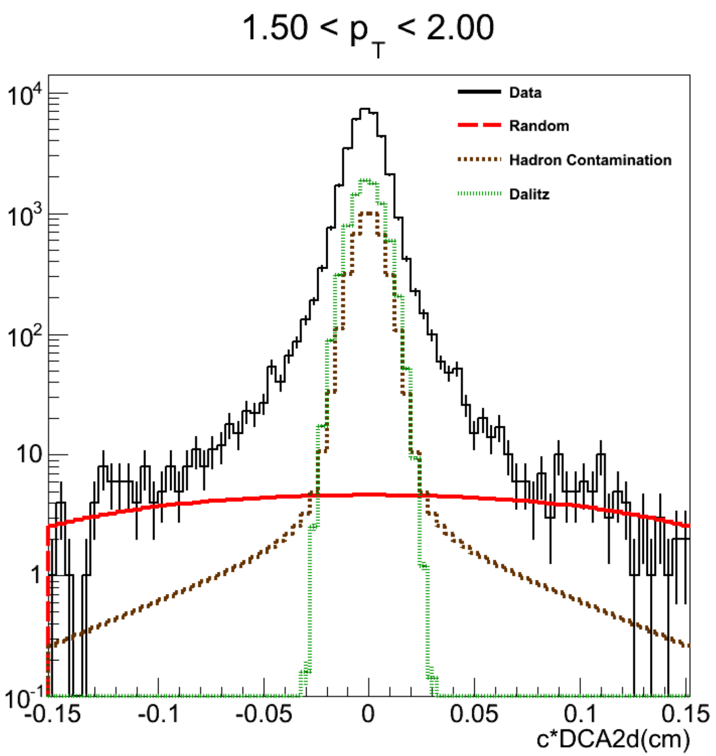

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<u>Dalitz:</u>
Monte Carlo shape
With measured yield

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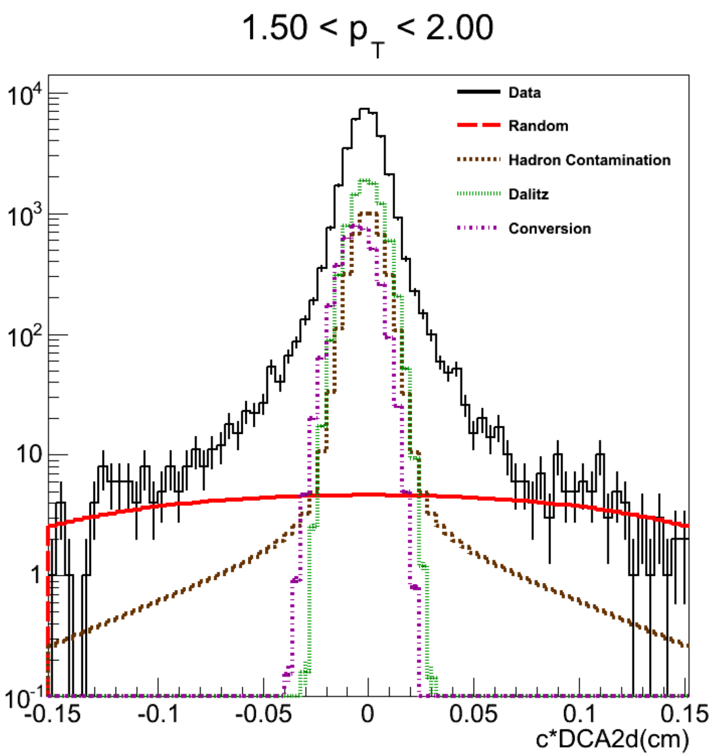

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Monte Carlo shape
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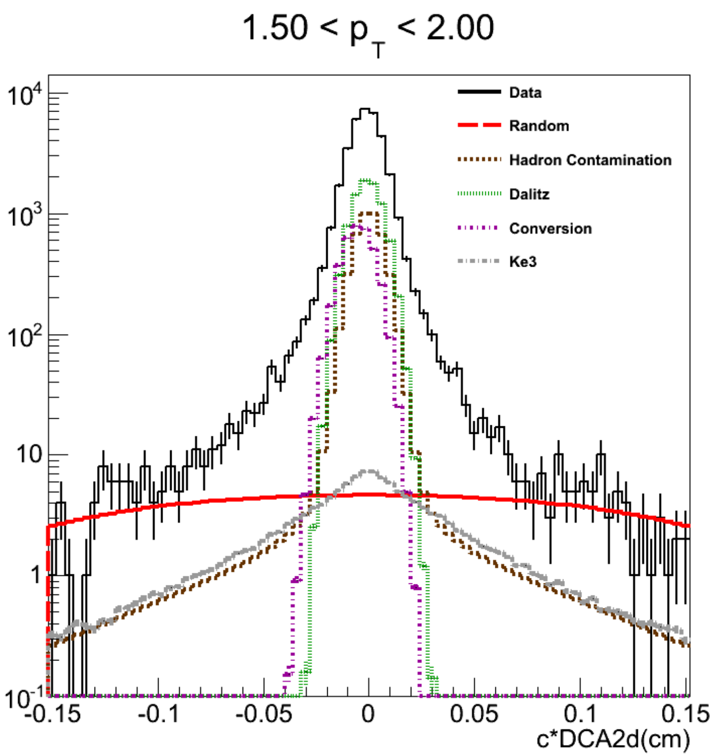
Conversions:
Monte Carlo shape
With Measured Pi0 yield
~75% rejected

DCA$_T$ Distributions: Backgrounds



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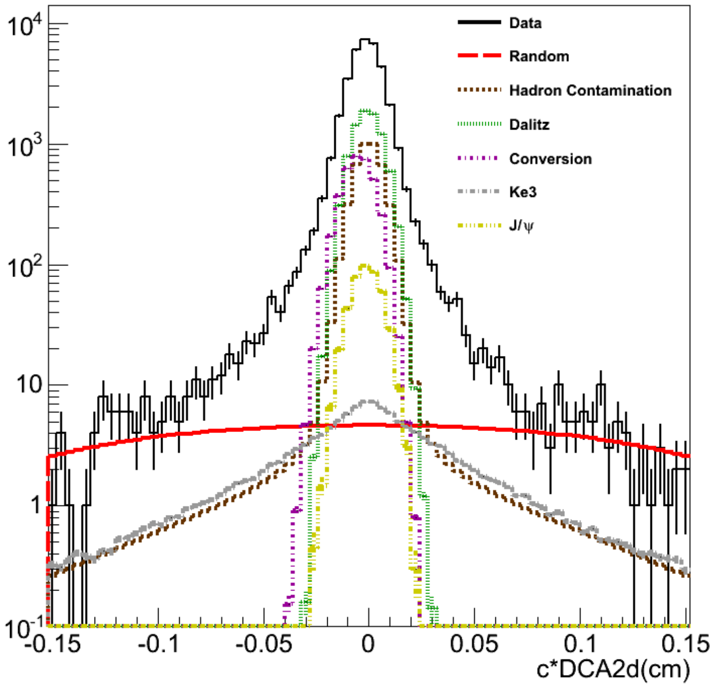
Monte Carlo shape
With measured yield

DCA_T Distributions: Backgrounds

1.50 < p_T < 2.00



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Monte Carlo shape
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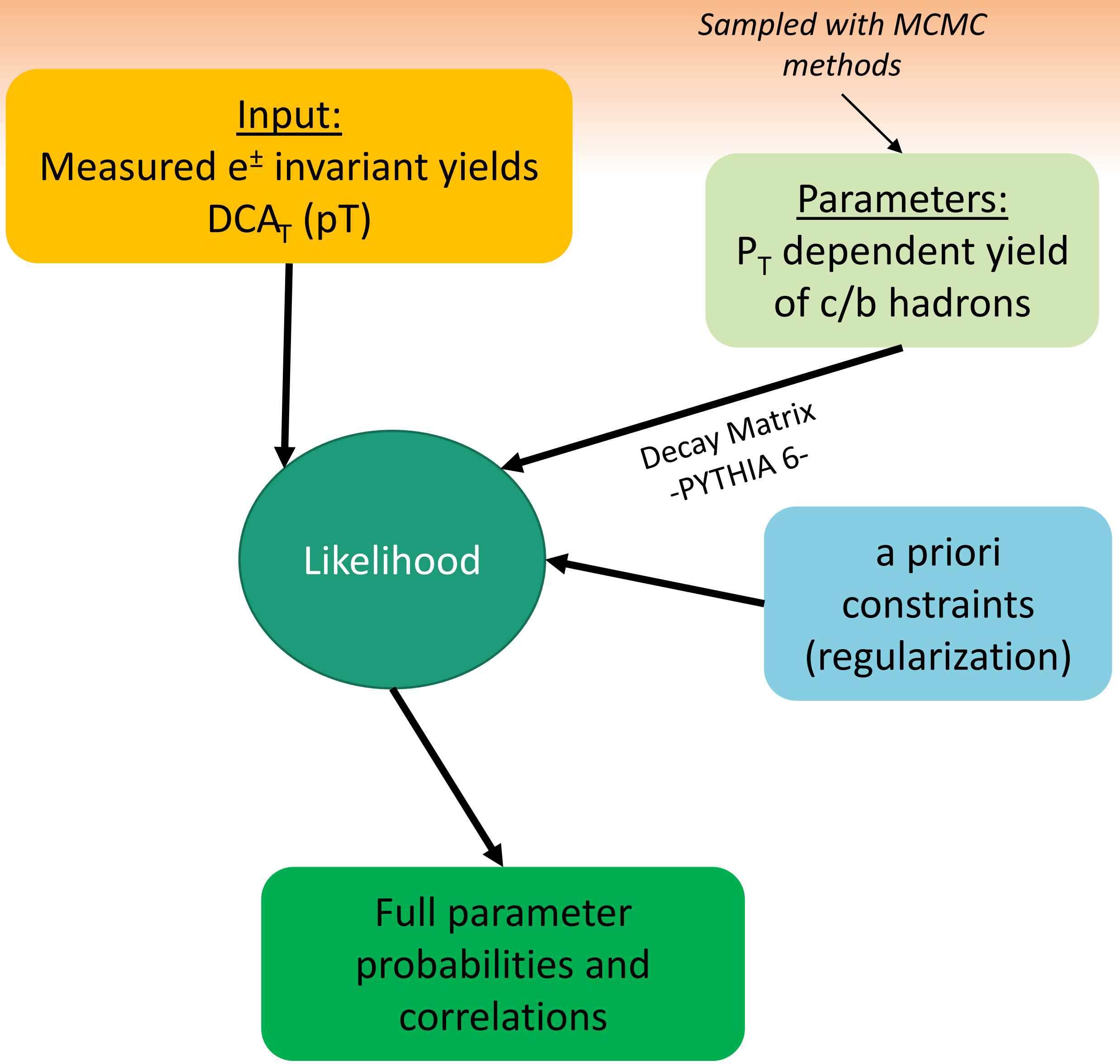
Ke3:
Monte Carlo shape
With measured yield

J/ψ->e^+e^-:
Monte Carlo shape
With measured yield

Unfolding

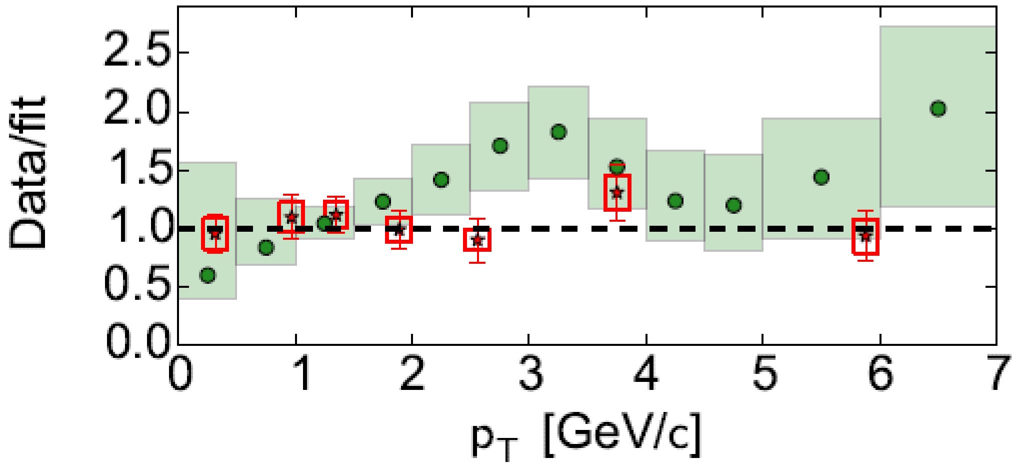
- The unfolding uses Bayesian inference methods to determine parent charm and bottom hadron p_T distributions
- Done through simultaneous fit to electron invariant yield and the 5 electron DCA_T distributions
- The decay matrix contains the probability of a bottom (charm) hadron with a given p_T to decay to an electron with a given p_T and DCA_T
  - Bottom := $B^{\pm}$,B^0, B_s, Λ_b (Includes B->D->e)
  - Charm := D^0, $D^{\pm}$, D_s, Λ_c
  - Modeled h->e decays using PYTHIA-6



Spectra agreement with data:

The unfolded D^0 pT spectra agrees within uncertainties with measurements from STAR

Phys. Rev. C ***93****, 034904 (2016)*



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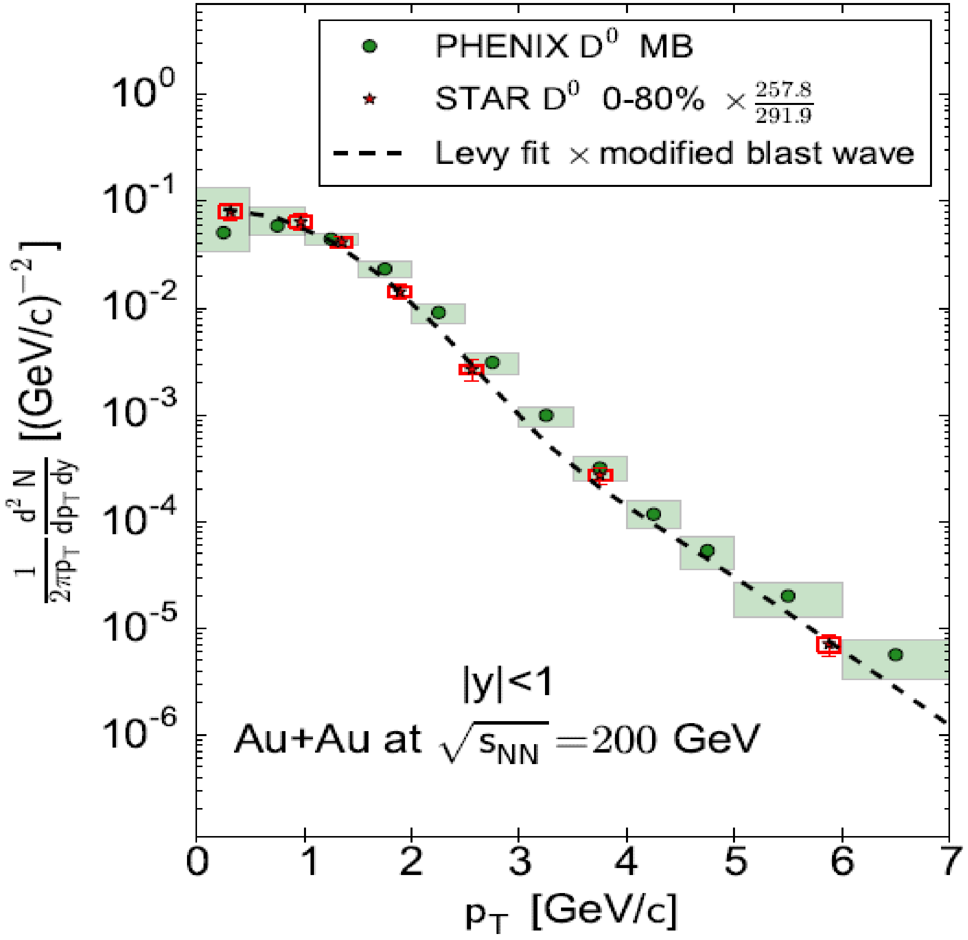


DcaT distribution and component refold

b → e

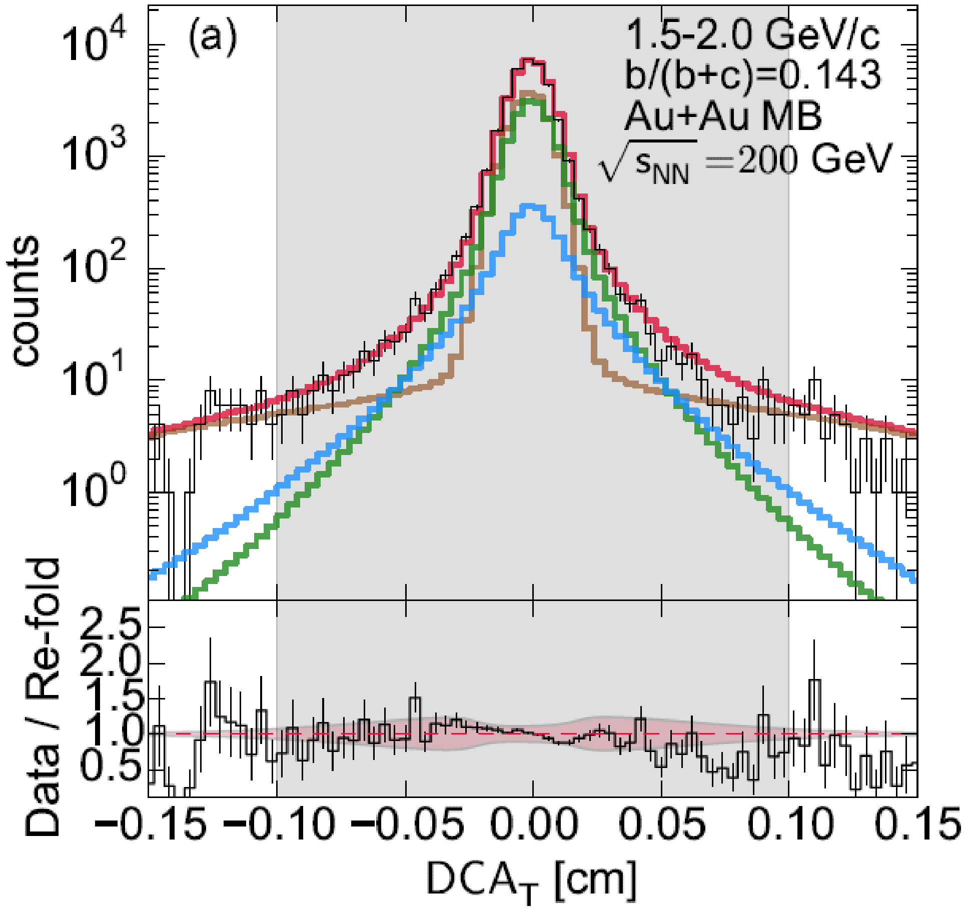
c → e

Total

Data

Backgrounds

*Phys. Rev. C **93**, 034904 (2016)*



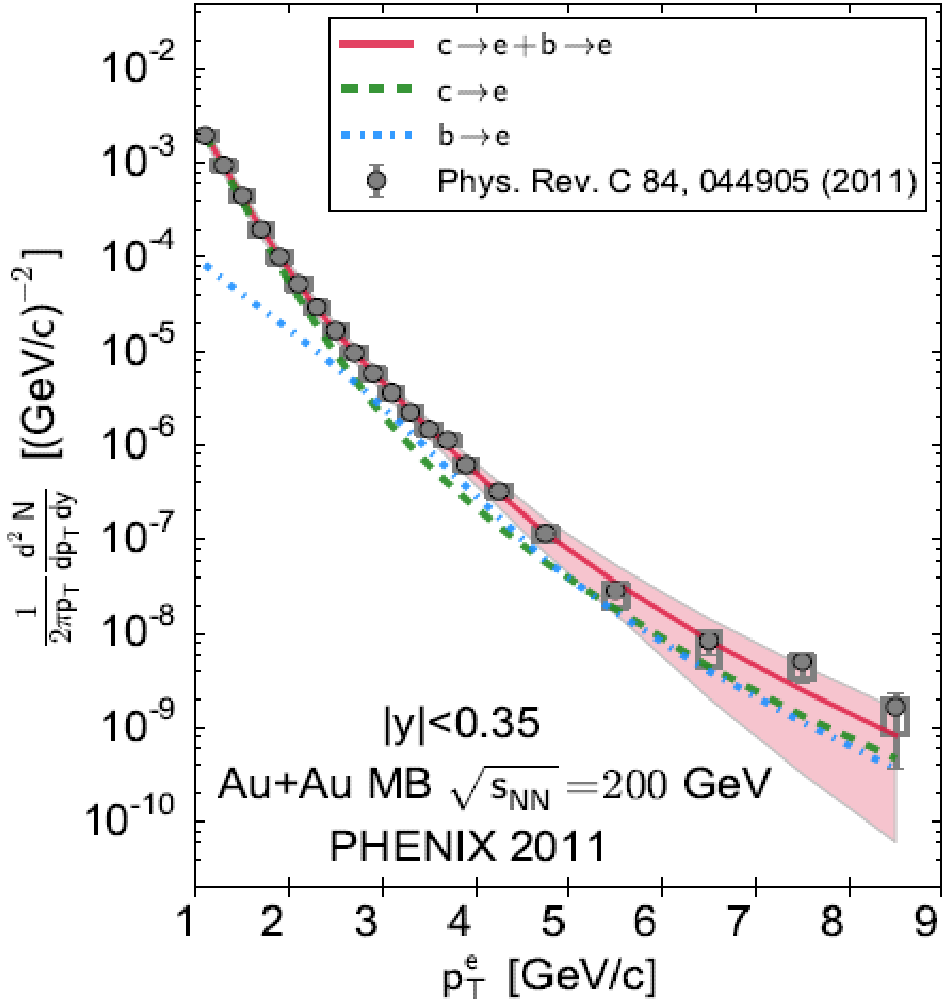
c->e:
Monte Carlo shape
Normalization from unfolding

b->e:
Monte Carlo shape
Normalization from unfolding

The charm and bottom yield predicted by the unfolding is consistent with electron measured DCA_T distributions.

Invariant yield

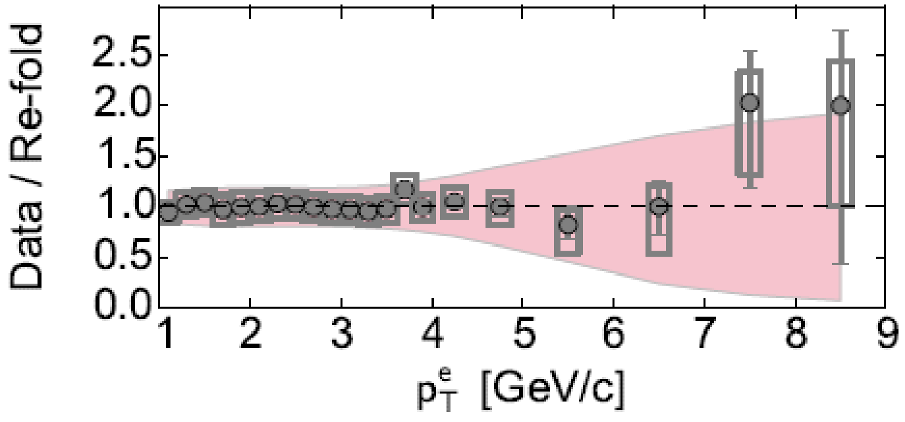
*Phys. Rev. C **93**, 034904 (2016)*



The unfolding results are consistent with the published inclusive heavy flavor electron invariant yields.

Between the 3.5->5 GeV range the bottom contributions begin to dominate those of the charm

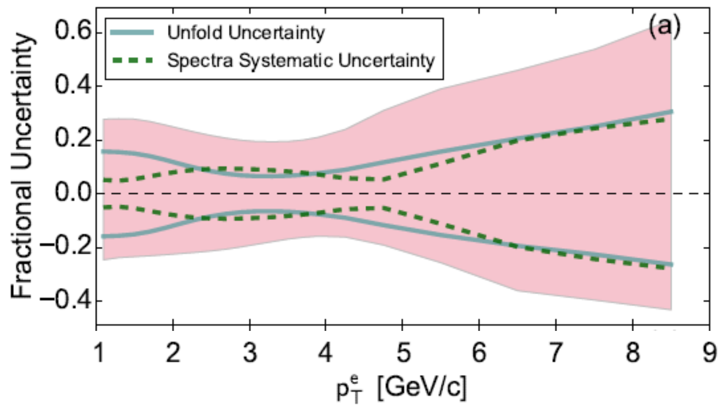
*Phys. Rev. C **93**, 034904 (2016)*



Uncertainties

- The unfolding directly takes into account statistical uncertainties
- Primary sources of systematic uncertainties:
  - Uncertainty in the heavy flavor electron p_T invariant yield

*Phys. Rev. C **93**, 034904 (2016)*



Uncertainties

- The unfolding directly takes into account statistical uncertainties
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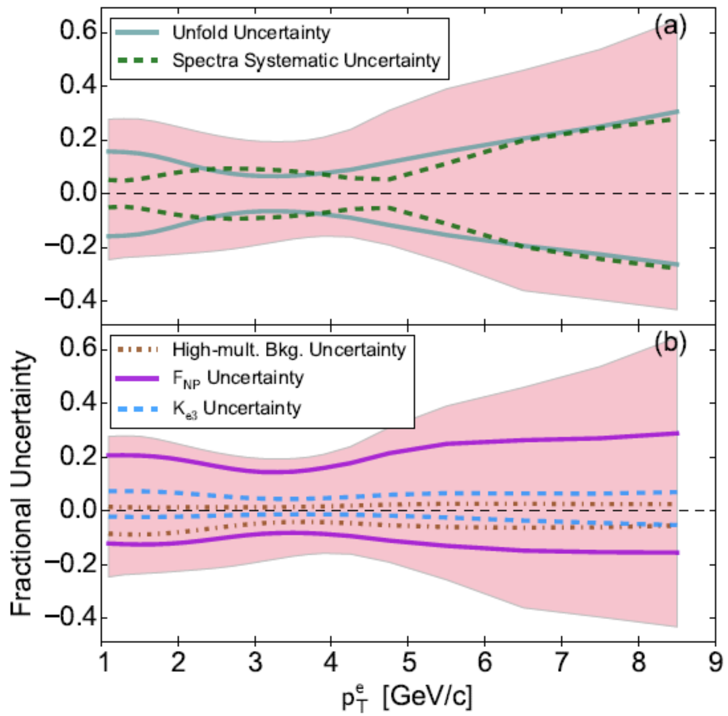
  - Uncertainty in the heavy flavor electron p_T invariant yield
  - Uncertainty in the high multiplicity background
  - Uncertainty in the fraction of non photonic contributions
  - Uncertainty in the K_{e3} normalization

Phys. Rev. C ***93****, 034904 (2016)*



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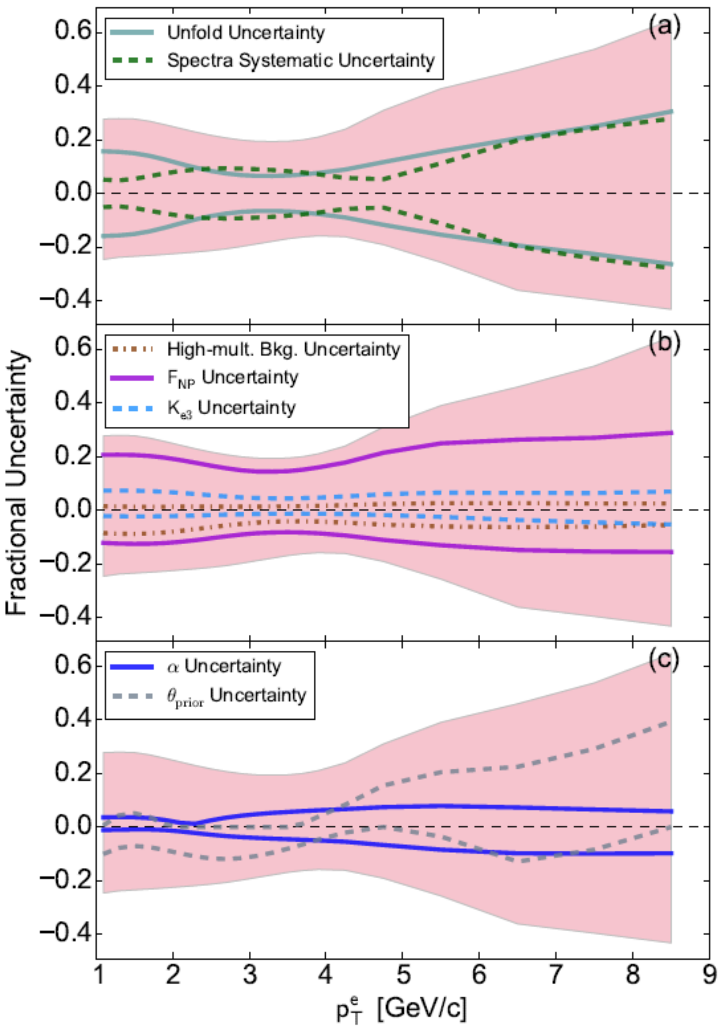
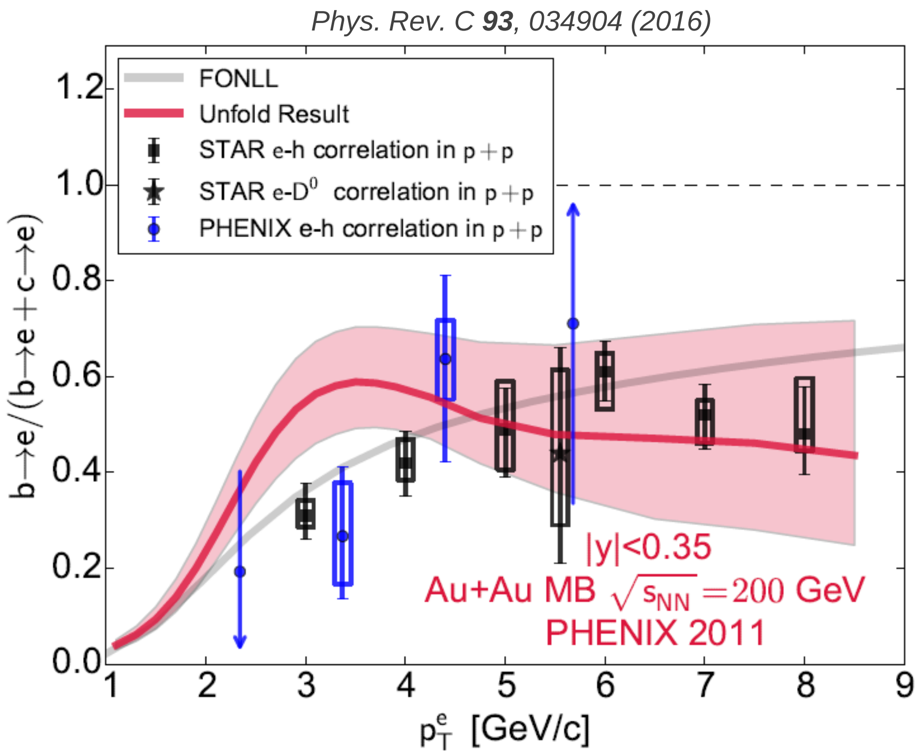
  - Uncertainty in the K_{e3} normalization
  - Uncertainty in the regularization parameter, and θ_{prior}

Phys. Rev. C ***93***, *034904 (2016)*



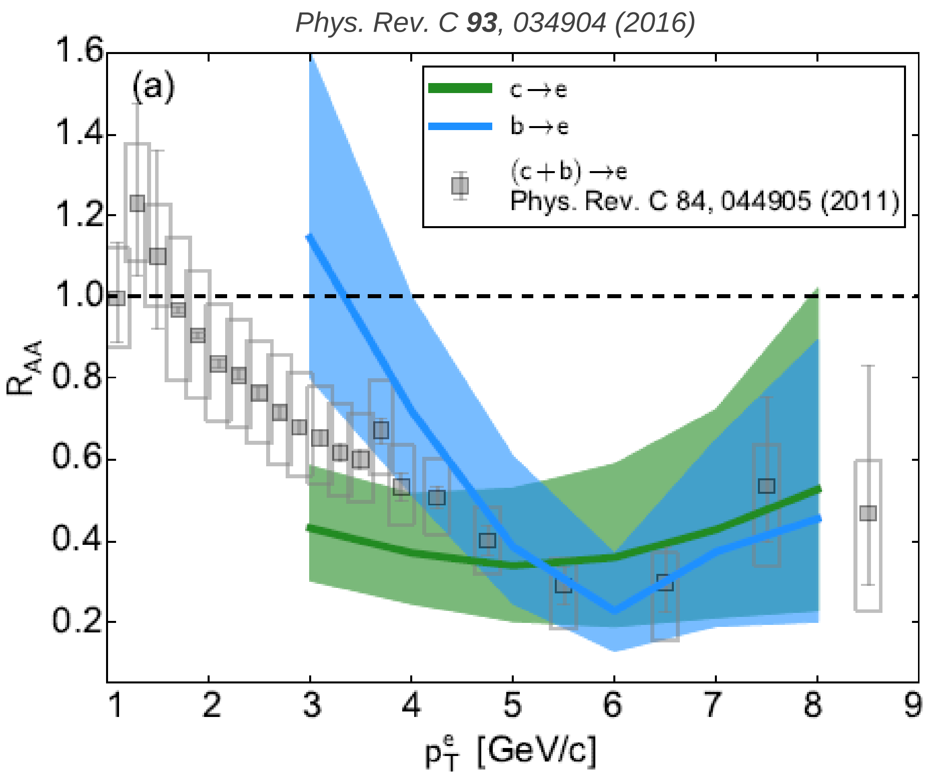
Measurement of Bottom and Charm results



The unfolded b->e fraction is consistent within the large uncertainties with previously published results from both STAR and PHENIX for p+p.

Implies that electrons from bottom hadron decays are similarly suppressed in Au-Au as the electrons from charm hadrons.

Bottom and Charm R_{AA}



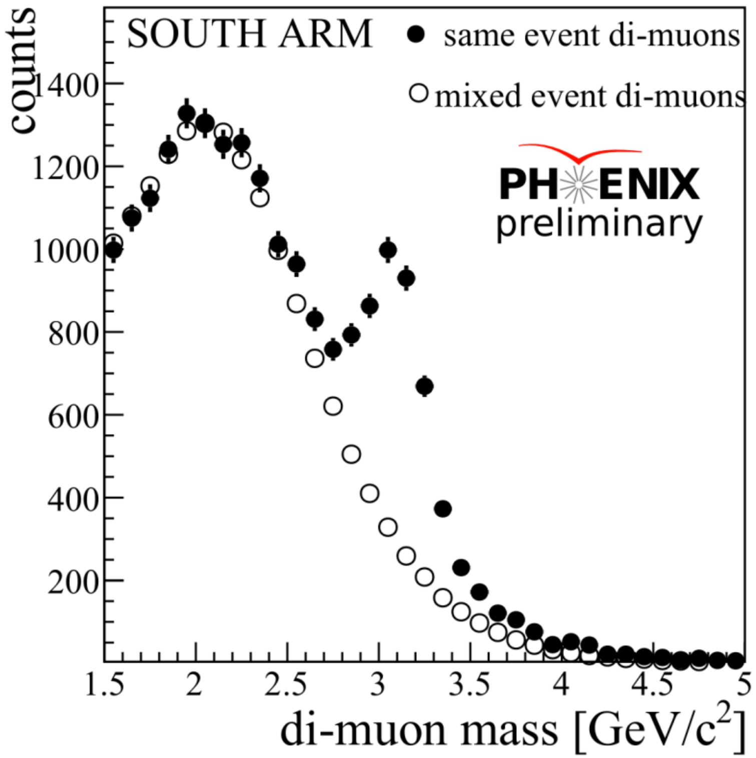
Using previously published p+p results from correlation measurements an R_{AA} was extracted for both electrons from bottom and electrons from charm.

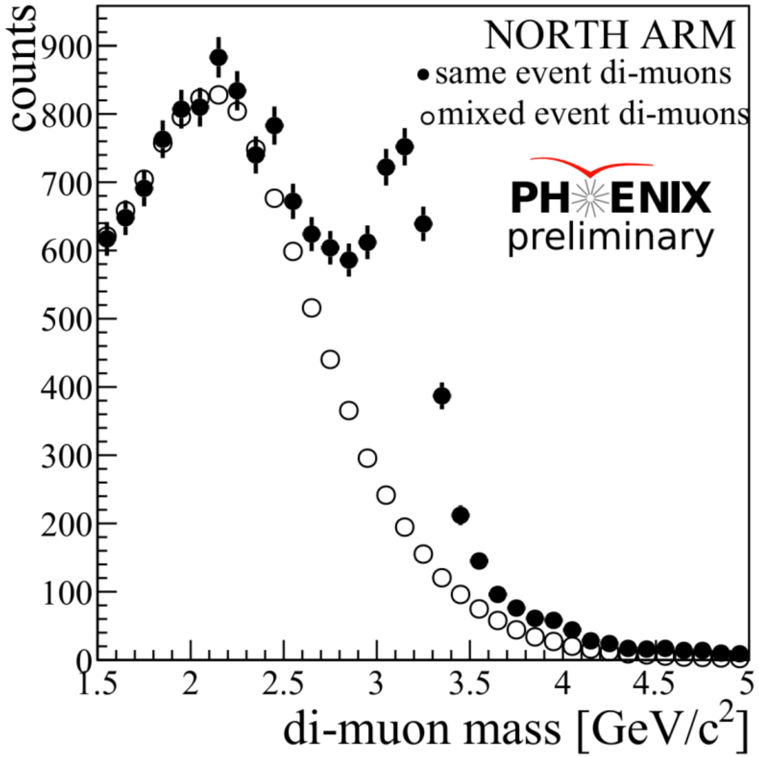
P+p results from:
A. Adare et al. (PHENIX), Phys.Rev.Lett. 103, 082002
1759 (2009), 0903.4851.

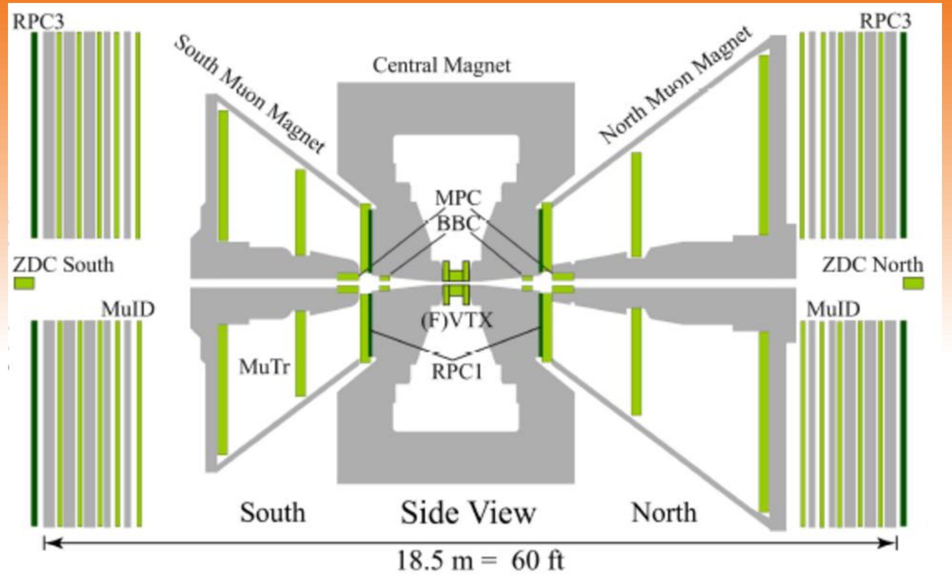
Reasonable agreement with the previously published inclusive electrons from heavy flavor R_{AA}

We see that around 3 GeV the electrons from bottom experience much less suppression than electrons from charm

Muons at forward rapidity







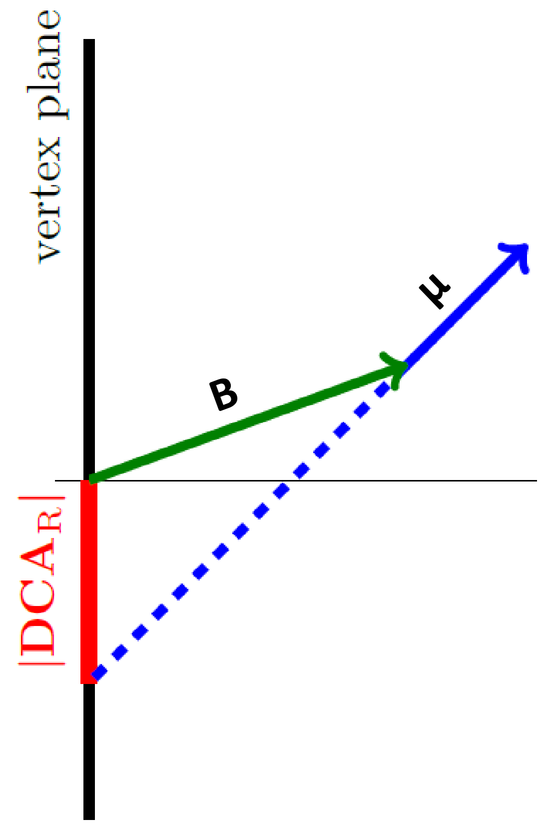
Using muon pairs in the J/Psi mass region an analysis was performed to determine the fraction from B-> J/psi decays

Muon Tracking with the FVTX

Muon tracks are reconstructed using the Muon Tracker (MuTr) with the Muon ID and are matched to stand alone tracks reconstructed in the FVTX

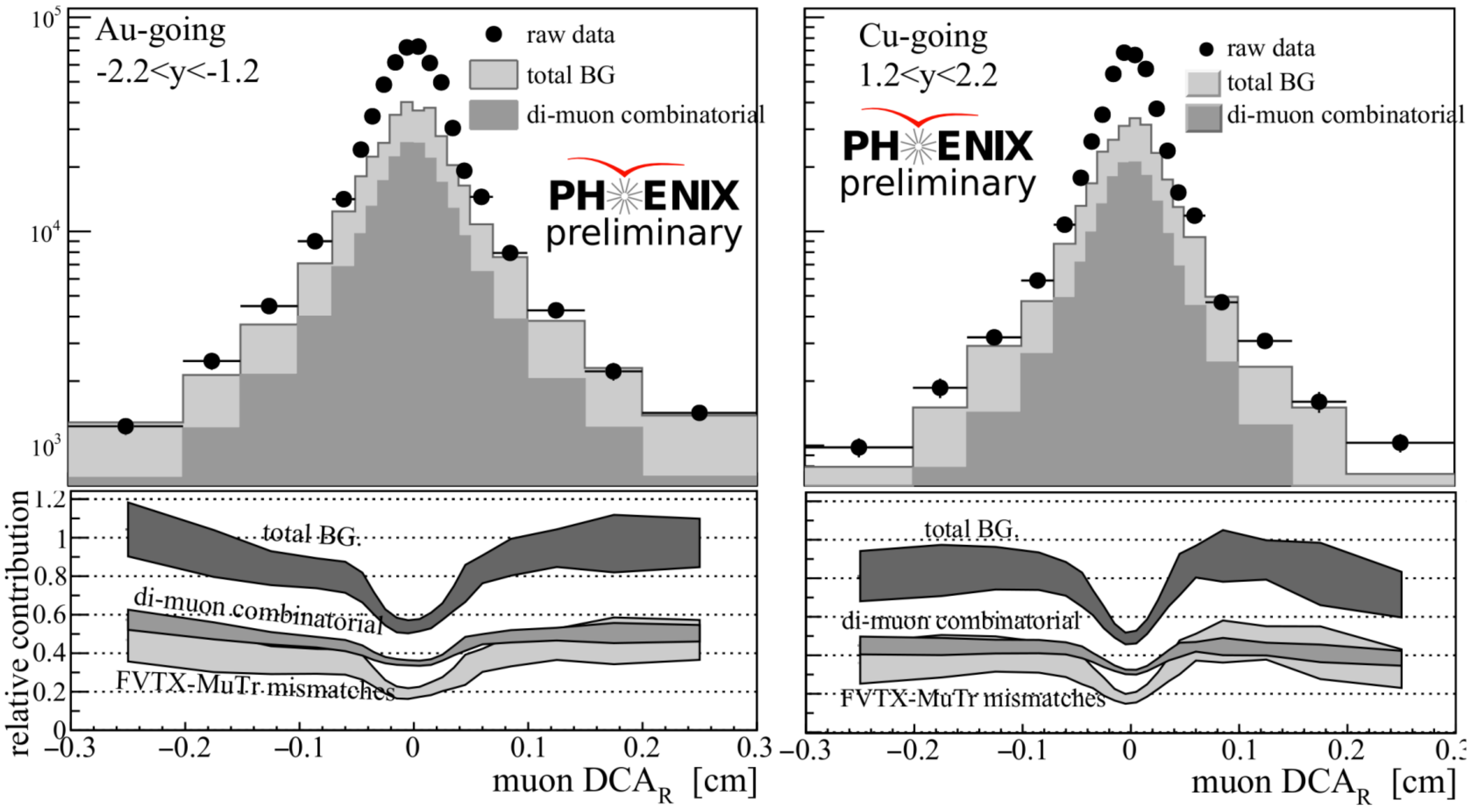
Miss-matched tracks were modeled using event mixing

Using the FVTX a DCA_R was measured, DCA_R is the distance between the projected position of a muon track to a X-Y plane located at the collision z vertex and the collision vertex projected along R.



Background components

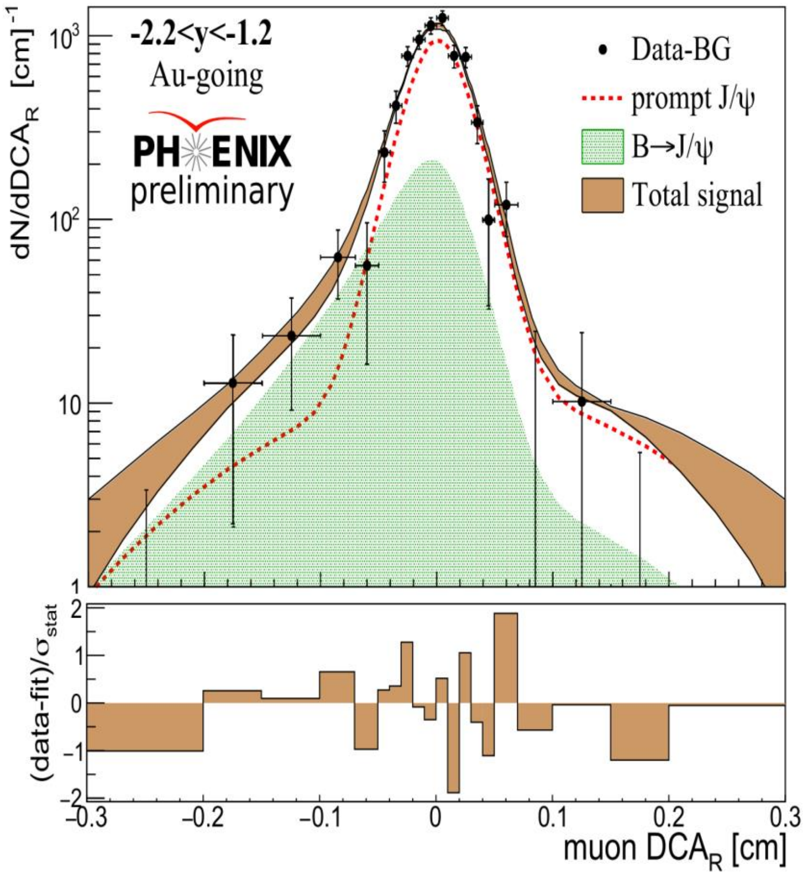
- Two sources of background:
  - Di-muon combinatorial
  - FVTX-MuTr mismatches: coming from incorrectly matching a MuTr track to the FVTX stand alone track.
- Signal templates and backgrounds are fitted together to extract the $B \rightarrow J/\psi$ fraction

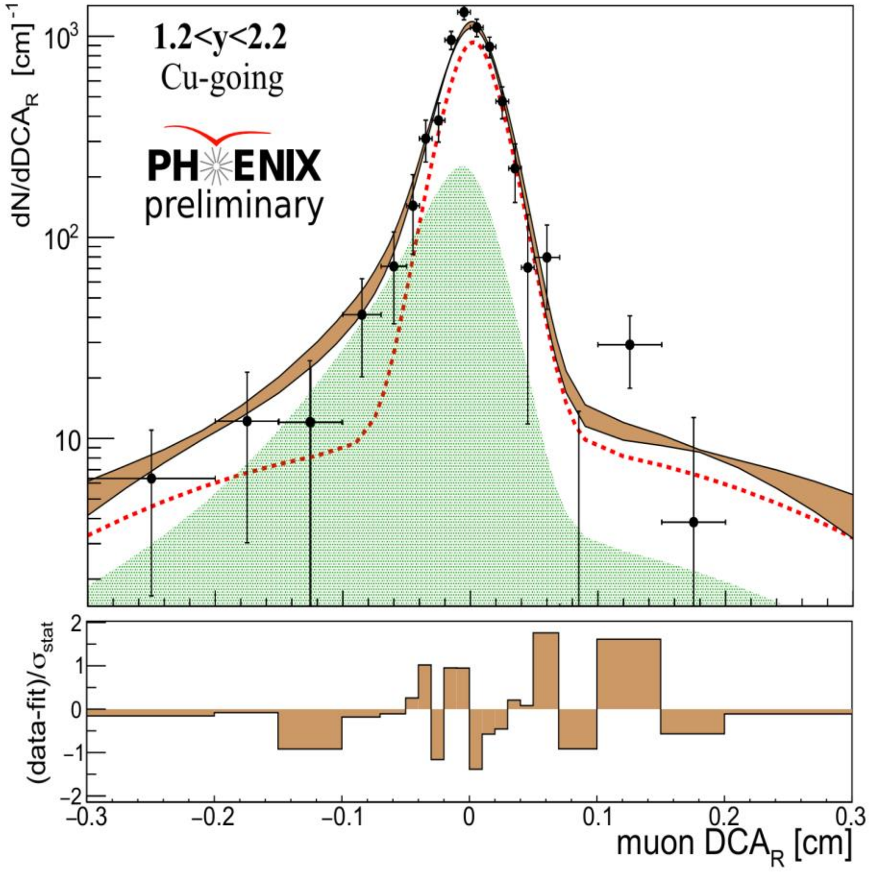


B→ J/ψ prompt J/ψ separation through DCA_R

- Prompt J/ψ and B-> J/ψ DCA_R template shapes, determined using MC simulations, were used in the fit
- The sum of the DCA_R contributions agrees well with the data as shown in the bottom panel

DCA_R Distributions for clarity are shown BG subtracted

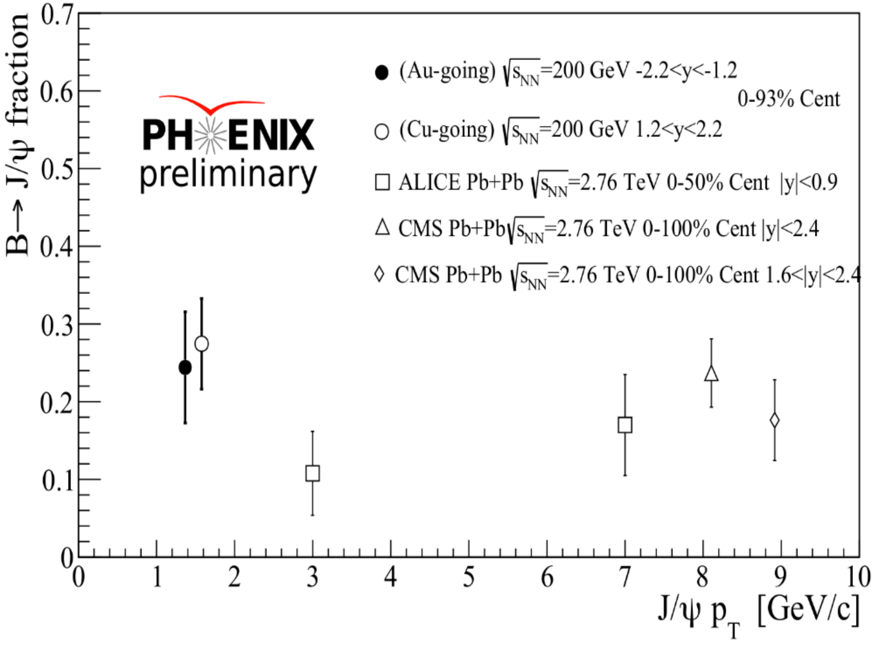


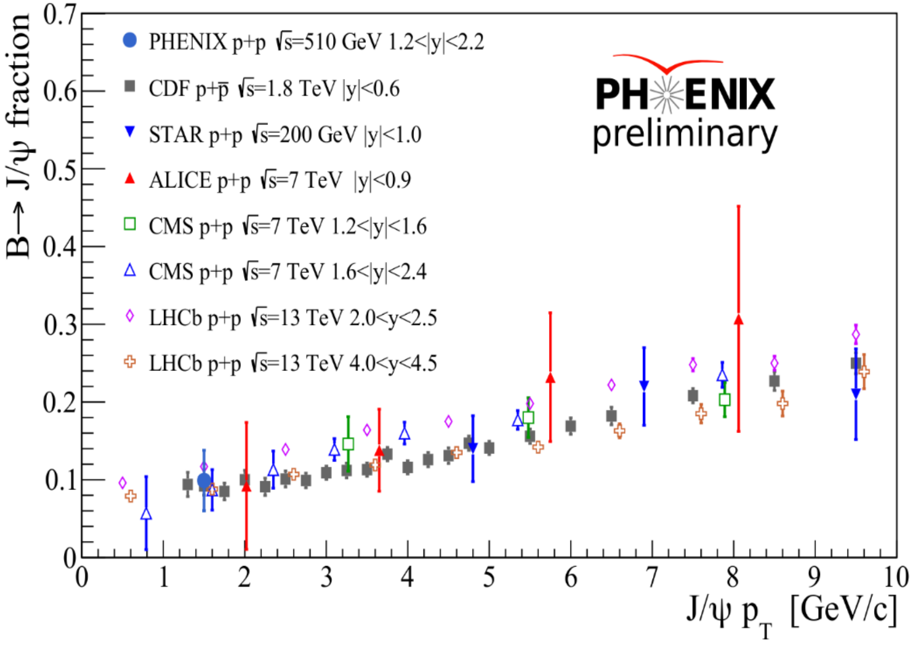


B->J/ψ fraction

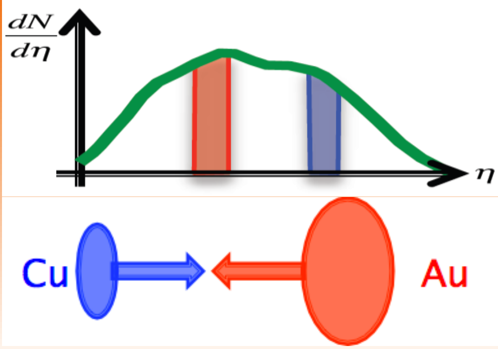
$F_{B \to J/\psi}$ was determined for both the gold and copper going directions.

Difference is attributed to a smaller suppression of B mesons relative to inclusive J/ψ at RHIC energies



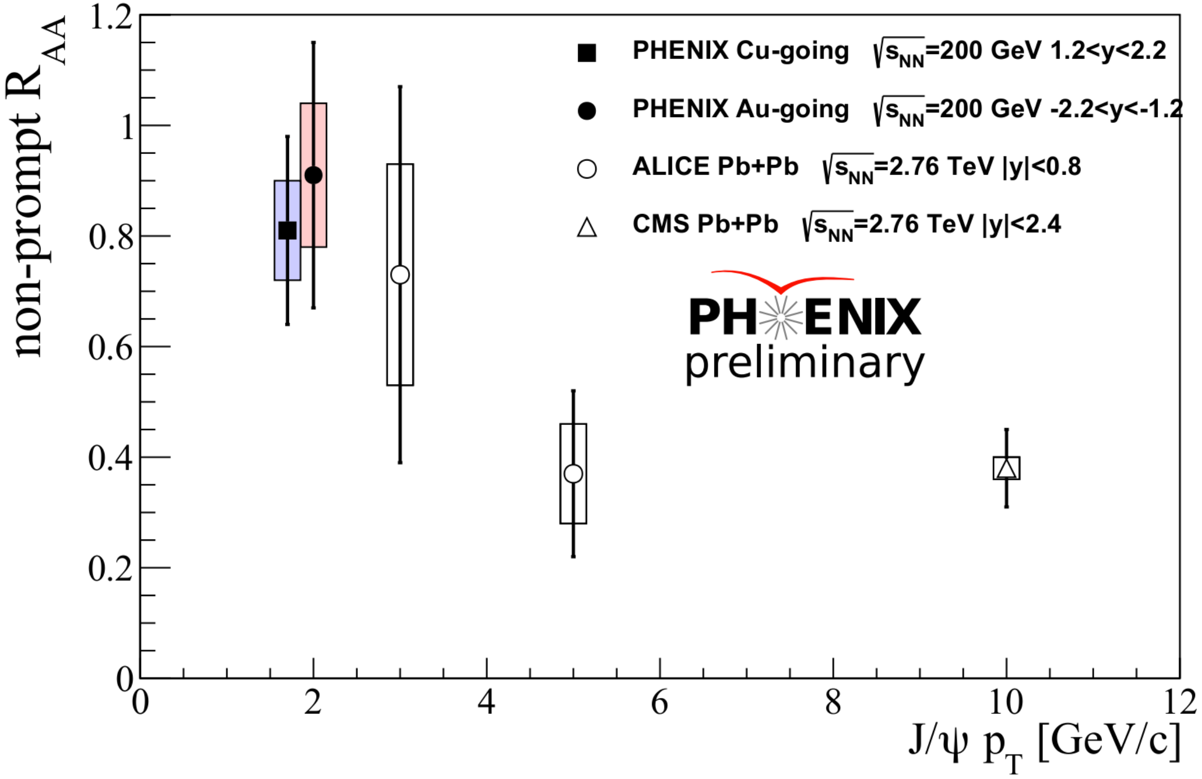


Non-prompt J/ψ R_{AA}



$$R_{AA}^{B\to J/\psi} = \frac{F_{B\to J/\psi}^{AA}}{F_{B\to J/\psi}^{pp}} R_{AA}^{J/\psi} = \frac{F_{B\to J/\psi}^{AA}}{0.1} R_{AA}^{J/\psi}$$

- The $F_{B\to J/\psi}^{AA}$ was taken from the B->J/ψ fraction, separately for the Au and Cu going directions
- $R_{AA}^{J/\psi}$ was taken from previously published results: *Phys. Rev. C90, 064908 (2014)*
- $\mathrm{F}_{\mathrm{B\to J/\psi}}^{\mathrm{pp}}$ was assumed to be 0.1 because there is no $\mathrm{F}_{\mathrm{B\to J/\psi}}^{\mathrm{pp}}$ world data at $\sqrt{s} = 200$ GeV.



Conclusions

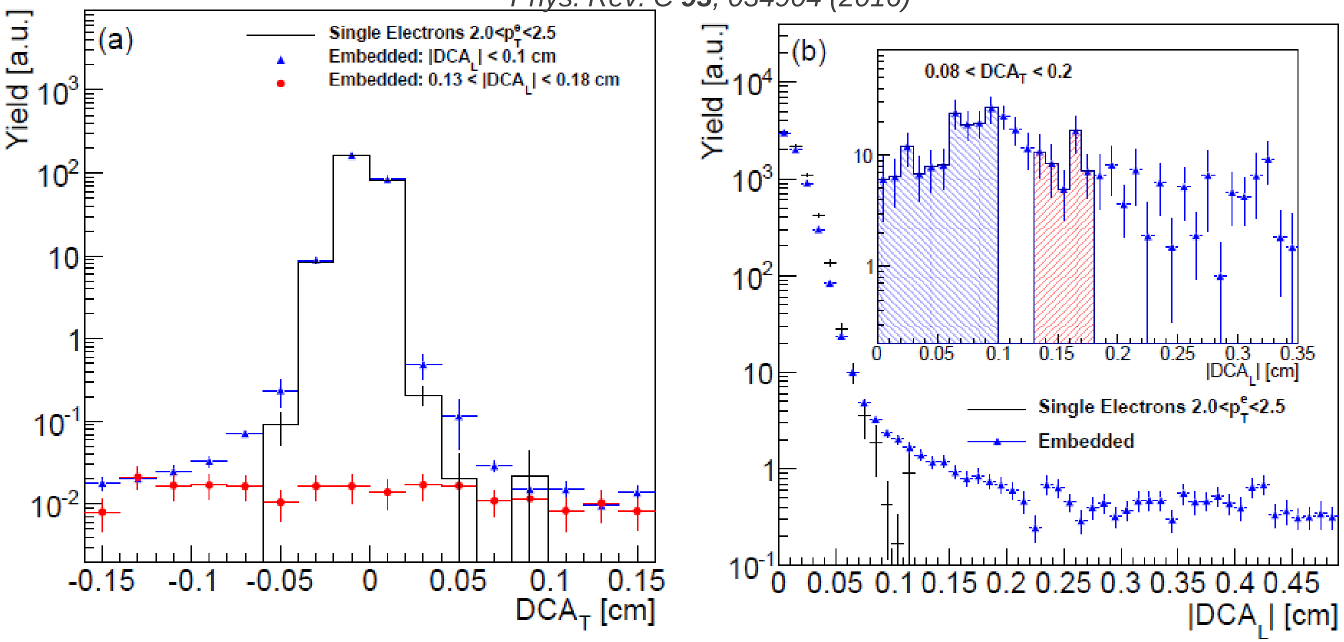
- We have had lots of exciting results coming out of PHENIX with regards to heavy flavor quarks.
  - Results on single electrons from charm and bottom decays at mid rapidity in Au-Au collisions agree within uncertainties with previously published results
    - Similar suppression of $b \rightarrow e$ and $c \rightarrow e$ at high-p_T
    - $b \rightarrow e$ is less suppressed than $c \rightarrow e$ at low-p_T
  - New preliminary results for forward rapidity B->J/ψ measurement in Cu-Au.
    - In Cu-Au at 200 GeV B-mesons at forward-rapidity are less suppressed than prompt J/ψ
- A unfolding analysis is now being done using the run14 AuAu data set, which is ~10x statistics, as well as with the run15 pp data set.
  - This will allow for a full R_{AA} and extend the results to a higher p_T range.

- There is a talk tomorrow in the Small System workshop by Xuan Li at 11:30 AM where she will discuss additional recent results from the FVTX

Backups

High Multiplicity Random Background

Phys. Rev. C **93**, 034904 (2016)



- Single electrons were simulated and embedded into real Au-Au events.
- High dcaL tracks are shown not to be physical and to come from random association tracks.

Conversion Veto

- Total VTX radiation length is 13%
- Conversion veto efficiency was tested using a full Geant3 simulation of the detector with hits running through the reconstruction software.
- The conversion Veto works by looking for two electron tracks within a pT dependent window, if two tracks are identified as being “too close” they are labeled as conversions and removed.

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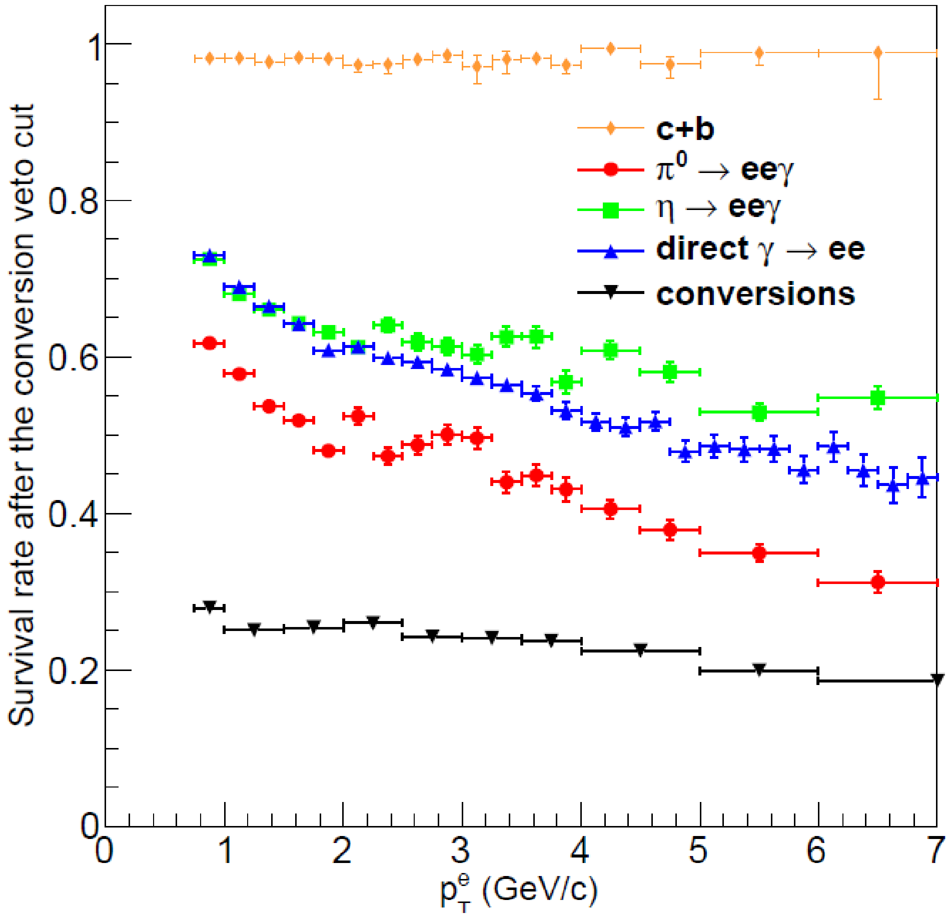
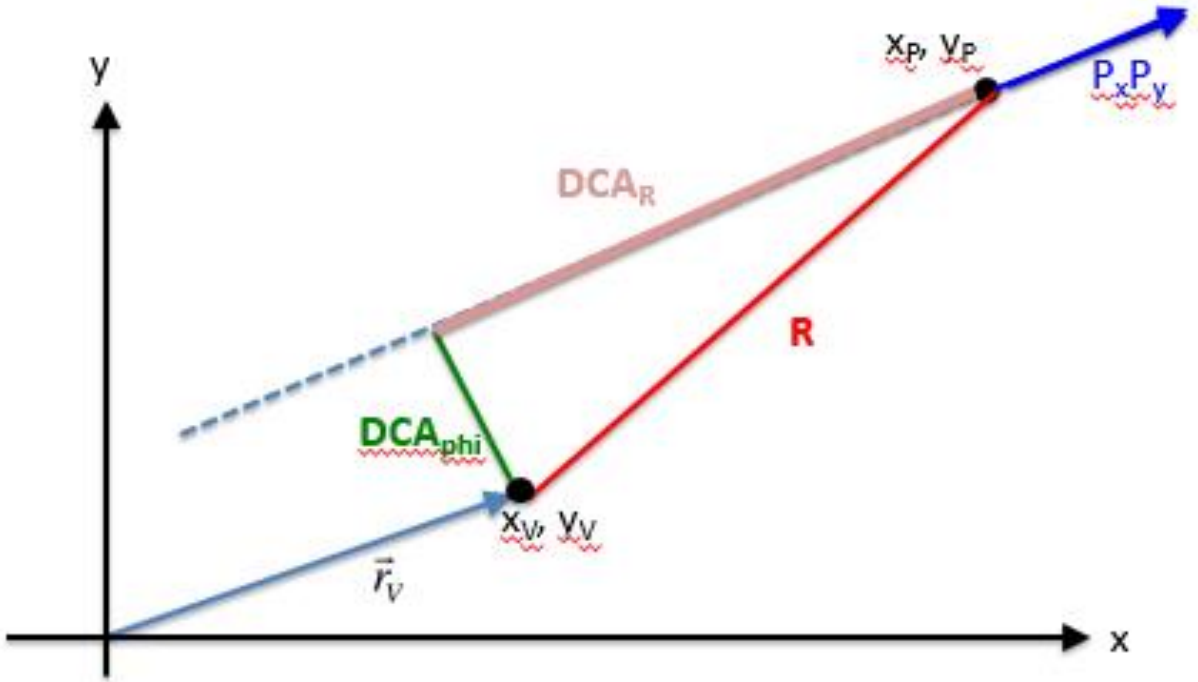


DCA_R Projection in more detail

The DCA_R is the projection along the vector defined by the PxPy of the muon of the separation distance between the projected muon position and the event vertex in the x-y plane at the z location of the collision vertex



J/ψ suppression in PHENIX and ALICE

Shows that for PHENIX the inclusive J/ψ at forward rapidity is more suppressed than in ALICE